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FIELD REPAIR OF COMPOSITE MATERIALS IN ARMY SERVICE: PLANNING FOR THE FUTURE

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POLYMER RESEARCH BRANCH

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ABSTRACT

A discussion of fiber-reinforced polymer matrix composite repair technology as it relates to Army requirements is presented. The organization of composite field repair research and development efforts within the Department of Defense (DoD) is reviewed. Recommendations are made for the establishment of a centralized Army composite field repair research and development effort. Ongoing composite field repair programs in DoD are listed in the Appendix.

CONTENTS

INTRODUCTION

Fiber-reinforced polymer matrix composite materials are being employed in ever increasing quantities in military vehicles and hardware, and have become a key element of the Army's drive to lighten the force. The rapid development of systems utilizing composite materials has, to some extent, outpaced the development of technology for the maintenance and repair of these materials. This problem threatens the readiness and maintainability of systems that contain composite materials and, as such, is an issue of vital importance.

Field repair of composites is a subtopic of the overall issue of composite repair. Field repair is not a well-defined term, as least in Army usage, and this is true in part because the Army has very little composite material currently in service. The major critical use of composites is in components of helicopters, most notably rotor blades on certain models, and these structures are not readily repaired in a field environment.

Prototype systems now under development, such as the Infantry Fighting Vehicle Composite Turret, illustrate the pressing need for an expanded awareness of and capability for field repair of composites within the Army. The objectives of this report are to identify the Army's needs in this critical area of materials technology and to determine ways in which these needs may be addressed.

DEFINITION OF THE PROBLEM

The definition of field repair varies greatly, depending upon the system or vehicle being addressed and the conditions under which it is used and serviced. To the Air Force, field repair means the servicing of an aircraft at a forward air base, complete with hangars, repair shops, electricity, material storage facilities, and trained technicians. Similarly, Naval field repair is primarily the maintenance and repair of aircraft on aircraft carriers. While slightly more restrictive than the Air Force environment, there are still many facilities available to the personnel performing the repairs.

In Army applications, field repair may be expected to have a much more literal meaning, especially in the case of ground vehicles employing composite armor. In the Army field environment, extensive facilities will not be available for fabricating repairs. This scenario applies a set of very stringent requirements to any proposed repair technique. Another consideration is that the Army may be expected to employ composite materials in a much wider variety of applications than the other services, which deal mainly with composites on fixed wing aircraft. Potential Army applications include hardened attack tactical shelters (HATS), howitzers, cargo containers, tactical structures (lightweight bridging), armor, and structural components of ground vehicles and aircraft. Each of these applications may impose unique requirements on repair processes and materials.

The Army requirement for composite field repair can be defined as follows: The level of repair that can be performed by the vehicle or system crew, using only the materials and equipment that can be carried along while performing their mission, that is required to allow continuation of the mission, or at least allow evacuation of the vehicle or system to a rear area.

The issues that must be addressed in developing a strategy for field repair of composites in Army materiel are as follows:

1. Materials: What adhesives or structural materials are currently available? What storage stability may be expected under wide ranging conditions of temperature and humidity? What are the properties (service limits) of the finished repair (and what is actually required)? What hazards (toxicity or others) are associated with a given material?

2. Expertise: How sensitive is the repair technique to the level of expertise of the personnel performing the repair?

3. Equipment: What specialized equipment is required to perform a given repair procedure? What are the power requirements of the proposed technique?

4. System Design: Can the structure of the vehicle or system in question be adequately restored to service using techniques and materials available to field personnel?

In the ideal situation, a single material or kit would exist that could effectively repair all composite materials in Army service, and restore the system to near original levels of performance with a minimum of expertise required to apply the repair. The materials making up this kit would have a storage stability of at least one year at 100°F.

The reality is that materials currently used for composite repair are usually system specific, require a high level of training to apply properly, are sensitive to storage conditions, and restore only a fraction of the system's original performance. They are typically not adaptable to composite field repair as it is defined here.

ORGANIZATION OF COMPOSITE FIELD REPAIR RESEARCH AND DEVELOPMENT PROGRAMS IN THE DEPARTMENT OF DEFENSE

Each branch of the military addresses the issue of composite repair in a different way. There are both formal and informal avenues for information exchange between the services, but there is no one agency which oversees these programs for all of DoD.

Army

Currently, in the Army, there is no unified approach to field repair of fiber-reinforced polymer matrix composite materials. Field repair technology is being developed on an ad hoc basis, generally as low level adjunct projects for the development of specific systems. Furthermore, there is very little composite repair development work being done, either in Army research facilities or under contract. It should be stressed that these observations refer specifically to field repair and not to higher level repair or remanufacturing techniques which tend to be somewhat better defined and therefore more easily addressed

Air Force

The Air Force has a well-defined composite repair program and a specific organization (Systems Support Division/Materials Laboratory) at the Air Force Wright Aeronautical Laboratories (AFWAL) at Wright-Patterson AFB, Ohio, is responsible for addressing the problems of composite supportability and repair. This includes field repair as the Air Force defines it. The Air Force also has repair R&D efforts going on at other facilities, such as the one at Sacramento Air Logistics Center at McClellan AFB in California, but the AFWAL group appears to monitor, and to some extent coordinate, the overall Air Force effort. The Air Force conducts large amounts of composite repair R&D on a contract basis, more than any other service.

Navy

The Navy has the most developed and complex composites repair R&D organizational structure of the three services. This is a consequence of having more composite materials in service than any other branch. The core of the repair R&D effort is carried out at the Naval Air Development Center (NADC) in Warminster, PA. The group there performs such diverse functions as chemical synthesis of resins and formulation development, structural engineering of repair designs, and development of complete repair techniques for specific types of composite structures. This organization appears to be closely interfaced with the Naval Air Depots (NADEPs) (formerly known as Naval Air Rework Facilities) around the country which are responsible for the maintenance and repair of specific systems. The NADC group provides training facilities for repair technicians from the NADEPs (and other government organizations), and the techniques and materials developed at NADC are field tested at the NADEPs, which provide feedback that assists the optimization of the technology.

IDENTIFICATION OF ARMY REQUIREMENTS FOR FIELD REPAIR OF COMPOSITE MATERIALS AND RECOMMENDATIONS TO ADDRESS THEM

Army Specific Requirements

The Army now uses or is in the process of developing major systems utilizing fiber-reinforced polymer matrix composite materials in the following areas:

- Aviation (helicopters)
- Armor (Infantry Fighting Vehicles)
- Shelters (HATS)
- Personnel protection (Kevlar helmet, vest)
- Artillery (howitzer carriage)
- Ground vehicles (truck bodies)
- Tactical structures (lightweight bridging).

With the exception of aviation, none of these systems' field repair requirements are being directly addressed by R&D programs outside the Army. Unfortunately, these requirements are not being addressed in any systematic way, if at all, within the Army.

Potential Applications of Existing Composite Repair Technology to Army Needs

The Air Force and Navy composite repair programs are mainly directed at depot level processes and do not directly address field repair in Army terms. In spite of this, the repair needs of the other services do have a certain amount of overlap with those of the Army, particularly in the area of materials. Virtually all repair strategies for composite materials involve the use of adhesive bonding, and the stability and performance requirements for the adhesives used are quite similar from one application to another. The Navy and the Air Force have ongoing programs to develop such materials, both in-house and contract efforts, and the results of these programs should be of great interest to the Army. Although less applicable to Army field repair requirements, some of the specific repair techniques and equipment developed by the other services could conceivably be adapted to Army applications. Appended to this report is a list of current research projects on composite repair, being performed by the Navy and the Air Force.

Recommendations

The Army would benefit from the establishment of a central organization, similar to those of the other services, with the responsibility for coordinating composite repair R&D within the Army, and with the Air Force and Navy. The principal benefit of centralization is efficiency. Currently, the development of general field repair (or battle damage repair) technology for Army systems (not necessarily composites repair) is the responsibility of the individual commodity commands. This decentralized approach has the advantage of allowing the organization most familiar with a given system to address its repair needs. However, this set-up undoubtedly results in the reinvention of various generic repair techniques by several organizations. In addition, there is the possibility that one organization or another will not acquire the best solution to a given repair problem if communication between the commands is insufficient.

A central composites repair organization could be expected to work with the commands to meet their needs, and would ensure that all Army users of composite materials have access to the same level of repair technology. This organization would have several tasks, which are detailed below.

1. Definition of Repair Requirements: For each vehicle or system, a requirement for repairability of the composite components must be set which details the most demanding conditions under which a repair will have to be performed and the minimum performance that the repaired item will be expected to deliver. This set of standards will be governed, in most cases, by the materials and equipment that can be made available to do the job. These standards would have to be determined in cooperation with the commodity command responsible for the system in question. In addition to operating standards for repairability, a set of repairability goals should be set also, to provide a target for R&D efforts to improve the repairability of the system. The standards should be updated periodically to take advantage of new technology as it becomes available.

2. Technology Capture: The Army needs to develop an active and ongoing technology capture/transfer function to acquire existing composite repair technology in an efficient manner and to keep abreast of continuing developments in the other services and in industry. This same organizational element could have the responsibility for performing the R&D functions required to evaluate the potential of technology developed elsewhere to meet Army needs. The final element of this function would be to transfer the technology to the commodity commands for implementation.

3. Advocate Repairability in Composite Systems Design: Because the Army systems which promise to incorporate large amounts of composite material are still in the development stage in most cases, it is possible to modify the designs to ensure that the structures are repairable. This may mean building in structural redundancy or reconfiguring main structural elements of composite components so that damage and subsequent repair is anticipated and provided for.

This burden should fall squarely on the contractors who design and manufacture Army materiel, and this goal should be aggressively pursued by procurement officials throughout the Army. Demonstration, by the manufacturer, of the repairability of new system designs must be a critical element of developing a field repair strategy for the Army. This demonstration should include complete specification of materials, equipment, and techniques, along with experimental data to authenticate the viability of the repair strategies.

The composite repair organization could be available in a consulting capacity to the procuring organization to provide expert advice and facilities to evaluate contractors' proposed repair techniques. (One of the NADEPs is now performing this function for repair techniques proposed by Grumman for the V-22). In this manner, future problems with maintainability of systems incorporating composite materials can be anticipated and avoided before the systems are fielded.

4. Perform Field Repair R&D for Specific Army Systems: As stated previously in this report, there are a number of composite-containing systems under development which are unique to the Army. The repair needs of these items are not being directly addressed by the other services, and do not appear to be under systematic investigation by the Army. The proposed composite repair organization would be expected to carry out R&D efforts directed at these Army specific systems, to develop repair techniques where none exist, and to advance the state-of-the-art of existing techniques. This work could be done both in-house and under contract.

CONCLUSIONS

The Army does not have a systematic approach to the problem of field repair of fiber-reinforced polymer matrix composite materials. There is no single organization responsible for overseeing field repair R&D and developing repair strategies for Army systems. The other services have such organizations, and their structure and operational methods could be adopted by the Army for use in solving Army problems which the other services do not address. The functions of a central repair organization would be manifold, consisting of a technology capture/transfer function, a design consulting function, and an R&D function. The need to develop such a capability is critical, since neglect of this area may lead to compromised functionality and loss of readiness in Army systems. The time to act is now, before the lack of such expertise impacts operational capabilities.

APPENDIX

Proposed and ongoing R&D projects in composite repair in the Department of Defense. The list is not comprehensive, and not all programs are described in detail. The purpose of the list is only to provide a sense of the scope and direction of current efforts. The basis for this list is review of composite repair R&D programs presented at a tri-service technical interchange meeting held at Boeing Military Airplane Co., Seattle, WA, November 1987.

AIR FORCE PROGRAMS

The Air Force composite repair R&D effort is the largest of all the services. A large part of this program is being done on contract. All the contractual efforts listed are administered by AFWAL. More detailed information concerning these projects is available from Mr. Mark Forte, AFWAL/MLSE, Wright-Patterson AFB, Ohio, 45433-6533.

Advanced Field Level Repair: A contract to Northrop Corp. (Hawthorne, CA), Phase II has just been completed. Phase I resulted in the development of the Moen heater, essentially a hot air blower which is used to construct a forced air oven around an area to be repaired. The device gives good control and versatility for a variety of repair configurations. It attains sufficient temperature to process high performance thermoplastics, as well as thermosets. A Phase III demonstration project is about to begin.

Depot Level Repair: A contract to Boeing Military Airplane Co. (Seattle, WA). The program is now in Phase II of a $300K/33 month effort. Research areas include contaminant identification, and water is the main interest here. Compton scatter radiography looks very promising as it detects all contaminants well. NMR, UV, IR, and microwave spectroscopy have all been rejected. Several methods for contaminant removal are being investigated. There is no one method available that is good for all contaminants.

Adhesive bonding to PEEK is under study. Boeing is now using "teflon etch," a proprietary formulation of sodium or sodium alkoxide. This treatment gives good bonds, PEEK-to-PEEK (5000 psi lap shear), without high temperature curing, using a commercial film adhesive.

Low Energy Curing Resins: This contract to Lockheed (Georgia) and Dow (Freeport, TX), started in March 1986. Its objective is to develop a resin with low temperature cure (sub 200°F), high T_g (over 250°F) with low moisture pickup, low viscosity, and long storage life (2 years at 120°F). The approaches being used include synthesis of monomers with increased functionality, translation of small reactive molecules through gelled systems, and synthesis of resins with rotational flexibility in their backbones. The best results to date have been obtained with vinyl esters/vinyl monomers systems. Heat distortion temperatures (HDT) of 235 to 351°F have been obtained, where toughness is compromised in systems with the highest HDT values. Moisture pickup in these materials is very low, under 2% in boiling water.

Post Failure Analysis: A contract to Boeing Military Airplane Co. (Seattle, WA), entails development of a strategy to diagnose the causes, sequence, and origins of failure in composites. The goal is to produce a handbook for failure analysis with a projected publication date of October 1988. The final test of the methods developed will be the analysis of deliberately damaged panels sent to Boeing (by the Air Force) to see if the damage process can be accurately identified.

High Temple - Filament Winding Process Development for 600 to 700^{O}F Matrix Materials: A contract to the University of Dayton Research Institute.

High Temple - PMR-15 Processing Development: A contract to McDonnell-Douglas.

Surface Protection/Paint Removal: This is a contract to Arthur D. Little (Cambridge, MA), started in FY88 and is an extension of an AFWAL in-house effort. The in-house effort has compared plastic media blasting (PMB), abrasive pads, chemical methods, flashlamp, ultrasonic putty knife, and laser stripping. The only approved process to date is hand sanding. In a typical example, an F-16 tail section with 28 coats of paint took 225 man-hours to hand sand. The Air Force is very enthusiastic about laser stripping, and a Phase I SBIR was just completed. The program developed a process using a 100 mW CO_2 laser divergent beam with about a one inch spot. The laser oxidizes paint to water and CO_2 with about 99.8% efficiency. The paint can be removed evenly, layer-by-layer, without disturbing the primer. The Phase II program to develop a portable unit with automated control is underway. Phase II will also evaluate the effects on the substrate (thought to be nil), residues, and ability to treat complex geometries.

NOTE: The Navy likes PMB and feels it can be used without causing substrate damage, a point of controversy. Protective coatings can be used to keep PMB from damaging composites as well. The Air Force maintains that inexperienced field personnel cannot be trusted to follow guidelines carefully enough to avoid substrate damage due to overpressure application or use of high hardness blast media.

Other approaches to be examined by Arthur D. Little include water jet, CO_2 pellet blast, excimer laser, and liquid nitrogen spray.

Thermoplastic Composite Supportability: To be awarded.

Induction Heating: To be awarded by AFWAL, cooperative with the Navy (NADC). The program is intended to qualify induction heating for repair processes using currently qualified resins/adhesives. There will probably also be a parallel effort in this program to develop new resin systems optimized for use with induction heating.

Hot Bonded Repair System: To be awarded.

High Strain Stability Critical Repairs: Cooperative with the Navy, this contract (to be awarded) consists of the development of field and depot techniques for the V-22 composite structures.

Composites Machinability Data/Guide: This program is a ManTech effort and an FY89 award is projected.

Rapid On-Aircraft Repair (ROAR): This is an in-house effort at AFWAL, started in FY84 and consists of evaluation of various available and developmental technologies. Systems investigated include Philadelphia Resins Box Patch, the Fenwal kit (glass/epoxy skin patch), Raychem heat blanket, heat lamps, RMX aluminum/composite patch, and the Windecker surface preparation (silane-based system for sub 200^{O}F cures, a nonacid system).

The RMX patch will repair circular/elliptical damage up to 7" cleaned up. Glass plies are saturated with resin, then the aluminum outer skin is riveted to the substrate or through-bolted on. Repaired panels show 125% of design limit load, but only 45 to 50% of original strength. This is not intended as a permanent repair. A video demonstration of the repair method is available from AFWAL.

Battle Damage Assessment Expert System: This program is in the early stages of development and is an in-house effort at AFWAL. Software is being written to run on IBM PC type systems to evaluate and recommend repair procedures for Aircraft Battle Damage Repair (ABDR).

Effects of Airflow on Damage Process: This effort is being carried out in-house at AFWAL. Test sections are damaged while under airflow induced loads, and the effects studied.

Northrop/USAF Supportability for F-5/T-38: This program is investigating the possible use of graphite/BMI or PEEK replacement parts on these aircraft.

Application of Advanced Composite Technology to Maintenance Problems: Sacramento Air Logistics Center (AF) is working to develop computer aided design and analysis (CADAS). They now have software available for VAX systems to analyze and design repairs for composite systems. This software is available for the asking to all DoD agencies. The Advanced Composite Program Office (ACPO) at Sacramento has a newsletter describing their activities.*

Continuing Problem Areas Identified by the Air Force:

- Paint removal
- Field level inspection (NDI)
- Long storage life prepregs
- Technology transition, lab - application

NAVY PROGRAMS

The Navy is the largest user of composites in aircraft currently in service with the F-18 (10% composite by weight) and the AV-8B (38% composite by weight). The V-22 VTOL craft under development will be over 50% composite by weight. The Navy also has the A-6 composite replacement wing program, now in production phase with Boeing. As a result, the Navy has a great deal of practical experience in the repair of composite structures and they have developed a number of proven techniques for a variety of composite damage situations. Almost all of the Navy's composite repair R&D work is performed in-house at NADC or the NADEPs. Training programs on composite repair are available to DoD personnel at NADC in Philadelphia and at the various NADEPs around the country. A point of contact at NADC for these programs is Mr. Tom Donellan, NADC, Code 6064, Warminster, PA 18974.

NOTE: The Navy is working aggressively to eliminate honeycomb sandwich construction from all new design work due to the large number of repair problems encountered with this design. Virtually all honeycomb has been removed from critical areas in the V-22 design. This is a good example of how repair problems can be avoided by timely input to the design process by R&D organizations.

Development of Ambient Temperature Storage-Stable Resins: This is a big priority for the Navy since there are limited cold-storage facilities on shipboard and poor control of temperature during shipping to remote locations. NADC has

*A point of contact for the publication is CPT Russell Keller at the ACPO, SALC, McClellan AFB, Sacramento, CA.

developed a two-part adhesive that can be stored at ambient conditions and is packaged in a correct mix ratio system that is relatively foolproof. The pot life is 72 hr. after mixing. NADC reports mechanical properties of the cured adhesive are equivalent to or better than commercial materials such as FM300 (Cyanamid) or EA 9321 (Hysol). They are now looking for a commercial producer of this material.

NADC has also developed a dimethyl hexanediamine cured epoxy system for prepregging which is stable in the B-staged state at ambient conditions for extended periods. This material is going into a demonstration project at the North Island Repair Facility in San Diego, California. Questions have been raised about the toxicity of the materials and possible OSHA restrictions on their use.

A bis-maleimide (BMI) based repair resin is under investigation at NADC. Currently demonstrated storage stability of this resin is three months at 100°F.

Dammage Assessment: A robotic ultrasonic scanner is under development at the University of Delaware. Further details are available from Mr. Robert Blake at NADC.

Generic Depot and Field Repair: NADC is developing, or has developed, several classes of repair ranging from skin repairs that can be performed at the field level to extensive structural repairs that must be done at a depot. These methods are demonstrated on large scale test sections at NADC to establish the ability to restore sufficient strength to damaged structures. The methods are then transferred to the field for application on actual aircraft damage.

Development of System-Specific Repair Manuals: NADC is developing battle damage repair manuals for the AV-8B and the CH-46 helicopter. The latter document should be of considerable interest to the Army. The Navy has also established a battle damage repair school at the Naval Weapons Center at China Lake, California.

ARMY PROGRAMS

The Army has the smallest composite repair R&D effort of the three services. Most of the composite repair development work in the Army has been performed at the Aviation Applied Technology Directorate (AATD) at Ft. Eustis, Virginia. These projects have focused exclusively on the maintenance of composite materials in Army aircraft. Programs currently exist at the U.S. Army Materials Technology Laboratory, Watertown, Massachusetts, and at AATD. Both of these programs are contract efforts and address specific systems.

Repair of Thick Section Fiberglass Composites (Composite Armor): This SBIR contract to Sunrez Corp. (El Cajon, CA) has just completed Phase I. The Phase I effort resulted in the development and demonstration of a light activated, fast curing resin system. This can be used with glass fiber reinforcement to produce patches for the composite armor being developed for IFV's. The advantages of the material include good storage stability, good adhesion, and rapid cure, even at low temperature, in ambient sunlight. A Phase II effort is under consideration which would involve development of a patch kit using this material, along with a portable light source for use in adverse conditions. The point of contact for this program is Mr. William Haskell, MTL, SLCMT-MEC, Watertown, Massachusetts 02172-0001.

Advanced Composite Structures Field Repair: This is a contract to McDonnell-Douglas Helicopter Corp. (Mesa, AZ). Its goal is to develop Army field level repair technology for existing and future composite airframe structures on Army aircraft. The final product of this effort is to be a description of a composite repair kit or kits for various Army aircraft. The program is still in the early stages of concept development. The point of contact for this project is Mr. Tom Condon, AATD, AVSCOM, SAVRT-TY-ASR, Ft. Eustis, Virginia 23604-5577.

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Michael S. Sennett

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